Multi-pronged events from Coulomb fission of nuclei at very low energies

B. Basu[1,2], S. Dey[1], D. Gupta[1,2], A. Maulik[1], S. Raha[1,2], Swapan K. Saha[1,2], D. Syam[3]

[1]*Centre for Astroparticle Physics and Space Science, Bose Institute, Kolkata 700091, India*
[2]*Department of Physics, Bose Institute, Kolkata 700009, India*
[3]*Department of Physics, Barasat Government College, Kolkata 700124, India*
(Dated: November 29, 2008)

Multi-pronged tracks have been recorded in the polyethylene terephthalate $(C_{10}H_8O_4)_n$ solid state nuclear track detector by exposure to a ^{252}Cf fission source. After chemical etching, two-prong to six-pronged tracks along with single tracks have been observed under the optical microscope. We carried out a systematic study to understand the origin of the prongs. The track detectors were coated with metals (Cu, Ag and Pb) and were exposed to ^{252}Cf source. After chemical etching two-prong to four pronged tracks were observed in each plate. We believe that at this very low energy of the order of 1 MeV/A, Coulomb fission is the only plausible explanation for the origin of such multi-pronged tracks.

PACS numbers: 29.40.Gx, 25.70.De, 25.70.Mn

The study of nuclear particles through track etching in solid state nuclear track detectors (SSNTD) is widely practised [1, 2] in the field of cosmic rays. The polyethylene terephthalate $(C_{10}H_8O_4)_n$ solid state nuclear track detector, commercially known as PET, has been used for the detection of heavy charged particles for many years [3]. This detector has some important advantages over the standard solid state nuclear track detectors CR-39, Lexan etc. The PET has a much higher detection threshold ($Z/\beta = 150$) [5] than that of CR-39 ($Z/\beta = 6$) and Lexan ($Z/\beta = 57$). The Z and β are, respectively, the charge and velocity (v/c) of a nuclear particle incident on the track detector. Our earlier studies [3] show that PET does not detect 6 MeV alpha particles from ^{252}Cf fission source. Further experiments confirmed that it does not detect 650 keV ($Z/\beta = 107$) alpha particles which has the highest stopping power in the detector material. The lower energy alpha particles were obtained by the degradation of energy. It may be noted that efficient detection of heavy cosmic ray particles requires that light charged particles including protons and alpha particles be eliminated, which are present as a large background. In this regard, the use of the PET detector is very advantageous [6]. Another big advantage of PET over CR-39 is that PET is a low cost detector and therefore very useful when large area exposure is required. As a PET detector, we have chosen a particular PET brand of CENTURY de'Smart, India, which is commonly used as over-head projector transparencies (OHP).

During a systematic study of PET characteristics, it was exposed to a ^{252}Cf fission source. Two plates each of CR-39 and PET were exposed to the fission source. One of the plates of PET detectors registered clear multi-pronged charged particle tracks (Fig. 1) along with single tracks, while the other detector registered only single tracks of fission fragments. The CR-39 registered both fission fragments and alpha particles and all are single tracks. These multi-pronged tracks of nuclei have been studied with the help of the calibration curve (dE/dx vs V_t/V_g). The dE/dx is the stopping power of the charged particle in the detector material, V_t is the track etch rate and V_g is the general etch rate. The dE/dx values were obtained using SRIM [4]. The calibration curve was obtained from studies of the tracks of different charged particles from radioactive sources (^{252}Cf) as well as ion beams from the accelerators. The charge response of this PET detector to light nuclei has been studied using 3.4 MeV/A ^{16}O-ions [5], using the air gap between the flange of the beam pipe and the detector as the energy degrader. The charge response has also been studied for heavy nuclei using 11.1 MeV/A U-ion beam, with aluminium foils of different thickness to degrade the incident energy to several values [5]. Calibration has also been carried out using 3.9 MeV/A ^{32}S and 2.7 MeV/A ^{56}Fe beams. In the present work, the data reduction was based on the measurement of the geometrical track parameters (lengths, angles and etched pit diameters). The estimation of the charge, mass and energy of the detected fragments show that the fragments lie between Oxygen and Cobalt.

The CR-39 (Intercast Europe Co., Italy) and PET films, each of area 3.5 x 3.5 cm^2 were exposed in vacuum (10^{-5} bar) for two minutes to the incident alpha particles and fission fragments from a ^{252}Cf source of strength 1 μCi. The thickness of the PET detector was 100 $\pm$ 5 μm and that of CR-39 was 600 μm. The etching of exposed PET and CR-39 detectors were carried out in 6.25N NaOH solution at temperatures of 55^0C and 70^0C respectively. Etching time was 4 hours which produced well developed tracks. The plates were scanned under different dry objectives (x100, x50, x20) of a Leica digital microscope, interfaced with a computer for image analysis. Two to six pronged tracks were observed in one of the PET films, along with single tracks (Fig. 1). The multi-pronged tracks were observed in a localized area of the detector. Figures of two-pronged tracks are not shown, as the tracks may correspond to elastically scattered particles. Fig. 1 (a-f) show spectacular multi-pronged events in uncoated PET. The numbers in (a-f) correspond to fragments, as depicted in Table 1. Fragmentation apparently resulted from the collision of the projectile with the
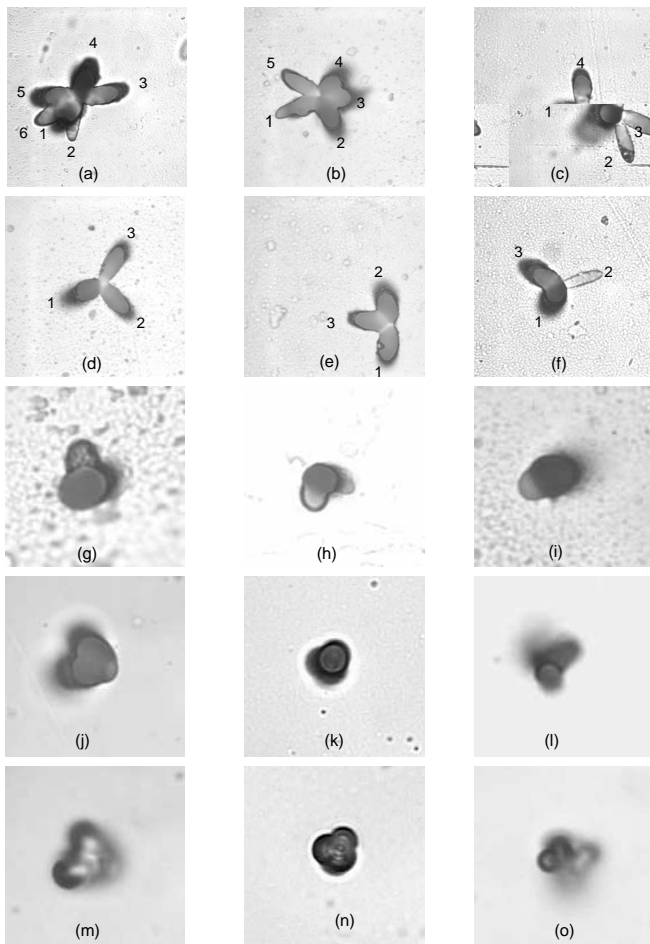
FIG. 1: Multi-pronged tracks in uncoated PET (a-f), Pb-coated PET (g-i) and coated CR-39 on the surface (j-l) and at a depth of 3 μm, 4 μm and 4 μm (m-o). The numbers in (a-f) correspond to fragments, as depicted in Table 1.

collimator (6 mm diameter, made of aluminium), shutter (made of lead) or the target holder (made of aluminium). To confirm the reactions we exposed a PET detector covered with 1 μm thick aluminized mylar foil. After etching, it showed a few two-pronged tracks, one three-pronged track and one four-pronged track. Photographs of multi-pronged tracks show that the tracks originate from single vertex. We have constructed the vertex for a few three-pronged events. A least square-fit calculation yields a vertex at a height of about 4 μm. The thickness loss due to etching is about 3 μm for four hours. Then it can be concluded that the fragmentation occurred on the detector surface or just above it. The observation of these multi-pronged tracks prompted us to initiate a systematic study on PET and standardized CR-39 detectors by coating them with different metals (coatings about 200 $\mu g/cm^2$) to see if these fragments are the result of the presence of these metals.

Fig. 1 shows the projections of the tracks on a horizontal plane. The actual angles between the directions of

emission of the fragments causing the tracks are given in Table 1, which also includes fragment charge and energy. Fig. 1 (g-i) show tracks formed in Pb-coated PET. We also used CR-39 coated with Cu, Ag and Pb. Fig. 1(j-l) show the tracks in Cu-, Ag-, Pb-coated CR-39 on the surface of the detector as well as more prominent projections of the tracks when focussed at 3 μm, 4 μm and 4 μm depth respectively (Fig. 1 (m-o)).

To calculate the errors in the data, we find that the standard deviation in the mean of the measurement of the depth of the tip of the etch cone beneath the surface is about 10 % (depth resolution of the microscope is 1 μm). The error in the general etch rate V_g, determined by the thickness loss method, is related to the number of measurements made at various points of the PET sheet and the average value of V_g. Error is taken as the standard deviation in the mean, which gives a value of about 5%. Combining these errors we get an error of about 10-15% in the determination of V_t/V_g which leads to similar errors in the determination of dE/dx from the dE/dx vs V_t/V_g calibration curve. The error in dE/dx leads to an error of about $\pm$ 3 in the determination of Z from the curve between dE/dx and R obtained using SRIM [4], where R is the range of the fragment in the SSNTD. This error in Z also leads to an error in the determination of energies of the fragments up to a maximum of about $\pm$ 30%.

As to the origin of these multi-pronged events, it appears that at this extremely low energy (energy of fission fragments being about 1 MeV/A) fragmentation of nuclei by the Coulomb force may be possible. It was proposed [7, 8, 9] that the Coulomb field of a heavy ion may distort a fissile nucleus so that it is slowly carried over the barrier with little internal excitation. Since the projectile energies are much lower than the Coulomb barrier, only electric forces are involved in inducing the process. If we compare Coulomb excitation with Coulomb fission, in the former case the nucleus is shot up to an excited state. In the latter case the nucleus is lifted through many states of collective excitation. If it reaches the barrier state, fission occurs. The Coulomb field actually exerts a torque which strongly aligns the nuclear symmetry axis perpendicular to the projectile direction. The maximum alignment occurs shortly after closest approach [9]. Consequently, in the rest frame of the fragmenting nucleus, the fission fragment distribution should peak at 90° relative to the projectile direction for binary fission. For fission resulting in three or more fragments the angles of emission can be quite different from 90°. Since in our case the projectiles are fission fragments of ^{252}Cf which are deformed and neutron rich, it is the projectile rather than the target (plastic track detectors in our case) which undergoes Coulomb fission. So in the lab frame the peaking of the distribution should occur at angles less than 90°.

We conclude by reiterating that the initial observation of the multi-pronged tracks was in a plain (uncoated) PET detector exposed to ^{252}Cf source while no multi-pronged tracks were seen in unexposed plates. In or-

der to check this conclusion, we got the plastic films coated with various metals before exposure to the fission fragments. The metal-coated detectors indeed reproduce multi-pronged tracks.

The present work may be the first observation of multi-pronged events from Coulomb fission at such a low energy. Further studies in this area as well as detailed theoretical analysis is presently being pursued.

[1] R. L. Fleischer, P. B. Price, R. M. Walker, Nuclear Tracks in Solids, University of California Press (1975)

[2] S. A. Durrani, R. K. Bull, Solid State Nuclear Track detection- Principles, Methods and Applications, Pergamon Press (1987)

[3] B.Basu, S.Banik, A.Mazumdar, S.Raha, S.Saha, S.K.Saha, D.Syam, Indian J.Phys. 79, 279 (2005).

[4] J. F. Ziegler, J. P. Biersack, The stopping and range of ions in matter (SRIM Computer Code), Version: 2003.26 (2003)

[5] B. Basu, S. Dey, B. Fischer, A. Maulik, A. Mazumdar, S. Raha, S. Saha, Swapan K. Saha, D. Syam, Radiation Measurements 43, S95 (2008)

[6] B. Basu, S. Biswas, S. Dey, A. Maulik, A. Mazumdar, S. Raha, S. Saha, Swapan K. Saha, D. Syam, Radiation Measurements 43, S262 (2008)

[7] L. Wilets, E. Guth, J. S. Tenn, Phys. Rev. 156, 1349 (1967)

[8] H. Holm, W. Greiner, Phys. Rev. Lett. 26, 1647 (1971)

[9] H. Kruse, W. T. Pinkston, W. Greiner, V. Oberacker, Phys. Rev. C 22, 2465 (1980)

Table 1: The charge, energy and angle between fragments. The first and second columns correspond to pictures (a-f) for PET(uncoated), as shown in Figure 1.

Fig. 1	No. of fragments	Charge and energy (MeV) of the fragments												Angle between tracks
		1		2		3		4		5		6		
		Z	E	Z	E	Z	E	Z	E	Z	E	Z	E	
a	6	10	18	14	35	14	37	14	40	16	45	11	20	$\theta_{12}=31^o$, $\theta_{23}=105^o$, $\theta_{34}=54^o$ $\theta_{45}=83^o$, $\theta_{56}=31^o$, $\theta_{61}=25^o$
b	5	18	60	20	30	17	50	9	16	13	30			$\theta_{12}=86^o$, $\theta_{23}=52^o$, $\theta_{34}=37^o$ $\theta_{45}=83^o$, $\theta_{51}=54^o$
c	4	21	65	12	25	16	45	17	50					$\theta_{12}=87^o$, $\theta_{23}=50^o$, $\theta_{34}=100^o$ $\theta_{41}=62^o$
d	3	13	25	15	43	19	52							$\theta_{12}=99^o$, $\theta_{23}=93^o$, $\theta_{31}=83^o$
e	3	12	20	10	15	10	15							$\theta_{12}=108^o$, $\theta_{23}=58^o$, $\theta_{31}=73^o$
f	3	12	20	10	17	11	18							$\theta_{12}=101^o$, $\theta_{23}=105^o$, $\theta_{31}=58^o$